T E C H N I C A L   R E P O R T

FREEZE-THAW CYCLE IN THE COASTAL ARCTIC OF ALASKA

By

Harold W. Searby
Regional Climatologist
Weather Bureau
Alaska Region
Anchorage, Alaska

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ARCTIC OF ALASKA

There have been no data recorded concerning the characteristics of the freeze-up and thaw of the tundra or water saturated marshes of the North Slope of Alaska.

Ice thickness and temperatures are available for a fresh water lake near Barter Island. The length of record is limited to three complete winter-spring seasons and two partial winter-spring seasons. The term winter-spring season covers the period from October through June. The only soil temperature data for the Arctic coastal region is from Barrow. The length of record is 1947-1956, although some data are missing.

The ice thickness and soil temperature data was analyzed as a basis for the following discussion. Because the amount of available data is so limited, no positive conclusions are made, however opinions are offered.

The current area of interest is the water saturated marshes. The following may prove useful in estimating the conditions in the marsh areas during periods of freeze-up and thaw.

The freeze-up period from its beginning in mid October through November showed little variation between the separate seasons. The most logical reason for this is the fact that they all start out even with regard to snow cover, which is none or nearly so. From December on through the thaw period in the spring or early summer, the rate of freeze and thaw showed more variance from one season to another, particularly in the spring months. The spring trend of both temperature and depth of snow cover on the ice most likely combine to cause the differences.

An ice thickness of 5 to 15 inches can be expected by the middle of October. By mid November it should range from 20 to 30 inches. The freezing process is more sensitive to the temperature trends during the early part of the freeze period, due to a still shallow ice thickness and little or no snow cover. For example, temperatures dropping below normal for several days in October show a corresponding increase in the rate of change of ice thickness within two weeks or less. Beyond about mid-November, when the ice has become fairly thick, and snow depths on the ice are greater, a plot of thickness against time shows a lag of nearly two months between a period of prolonged cold and the resulting effect on the ice. Degree days using a base of 32°F was used to see if this much lag was real. Little if any change was noted.

For the seasons in question, maximum thickness was reached between March 31 and April 15. The maximum thickness varied from 84 inches in 1966 to 58 inches in 1962. The period of maximum thickness lasted from one to four weeks. Correlating the period of coldest winter temperatures with the time of maximum ice thickness we see that the trend of increasing thickness continues until the mean temperature is about two months beyond the coldest for the winter, and has warmed to between minus 10 and zero degrees. The dates on which the ice showed a decrease in thickness were quite variable, occurring as early as

April 5th and as late as May 20th. The mean temperature at the time the thickness began to decrease varied from a minus 4 degrees to 19 degrees, indicating that the reaching of a particular temperature is no help in knowing when the ice would begin to decrease in thickness. In only three of the four cases had measurements been continued until the thickness reduced to 20 inches or less. For these three the mean temperature at the 20 inch thickness value was between 37 and 40 degrees and the dates were between June 24th and July 4th. Remarks accompanying the observations of 20 inches or less indicated puddles of water on the ice, numerous cracks or leads of open water during the latter half of June.

Figure 1 is a graphical depiction of the four seasons studied, and clearly shows the effect of prolonged periods of colder and warmer than normal temperatures. For example in 1962 a thickness of 40 inches was reached 70 days after the latest date of the other three cases. Temperatures for January and February were as much as 10 degrees above normal for a period of at least four weeks, causing the freezing trend to slow and actually come to a stop for a short time in late February. A second example is the 1965-66 season, when temperatures were below normal beginning in early December, and averaged five or more degrees below normal during February, March and April. The result was a maximum thickness of 84 inches which was 13 inches more than for any other season. The long period of no change in thickness during February and March is not compatible with the below normal temperature. All observations during this period were identical which is not likely to happen. It is suggested that that portion of the trace be considered unreliable. Since the depth of snow cover over the area in question is also a controlling factor in the rate of freeze, it is plotted in figure 1a for the ice seasons studied. It is difficult to know how much influence to attribute to snow depths and how much to temperature. However, we can safely say that a thick cover of snow will influence the rate of freeze, making it more gradual even though the temperature may average many degrees below the normal. It will also slow down the decrease in ice thickness in the spring, even in cases where the temperature may be well above the normal. The 1965-66 season is a good example of this. The deep snow cover during April and May kept the ice thickness constant. In late May the snow cover disappeared fairly rapidly and in June the ice also showed a rapid decrease in thickness.

Table 1 represents a tabular depiction of the dates of and mean temperature on the day of specified ice thicknesses. Table 2 gives climatological information for Barter Island.

The only soil temperature data for the Arctic coastal region is from Barrow. There are variations in climatic conditions between Barrow and Barter Island, which would make direct application of the Barrow data to the eastern Arctic unadvisable. However, as in the case of applying fresh water lake freeze-up thaw data to water saturated marshes, it is reasonable to believe that limited application is feasible. Whether marked soil differences exist between the two general areas is not known. The presentation of the soil data here is by reproduction of selected pages taken from Technical Report 105, dated May, 1965 and

titled "Ground temperature Observations, Barrow, Alaska". The temperature observations were made by the U. S. Weather Bureau for the Corps of Engineers, U. S. Army, the compilation and publication of the data was done by the U. S. Army Material Command through its Cold Regions Research and Engineering Laboratory at Hanover, New Hampshire (now known as U. S. Army Terrestrial Science Center).

Results from the soil temperature summarization that are of special interest to the developments now in progress in the Arctic are the depth of the freeze-thaw layer (depth to permafrost) of two and a half feet, and the lag that exists between maximum solar heating and temperature maximum in the soil.

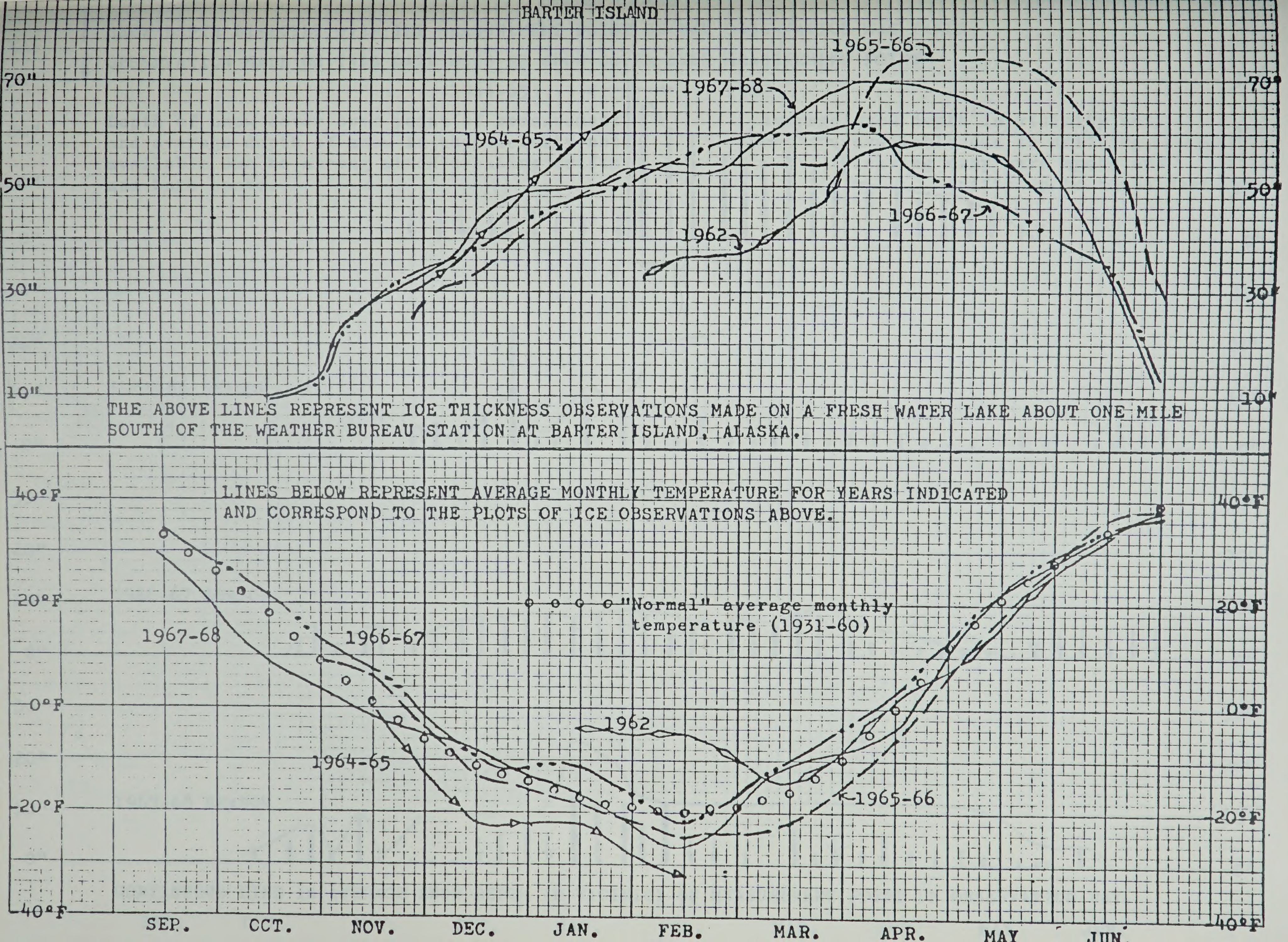
Table 3 gives climatological information for Barrow. Figure 2 shows the installation of the temperature sensing equipment.

Although winter working conditions in the Arctic, created by the climate of that region, are a different subject than that of this paper, the matter is of extreme importance, justifying its being covered briefly at this time.

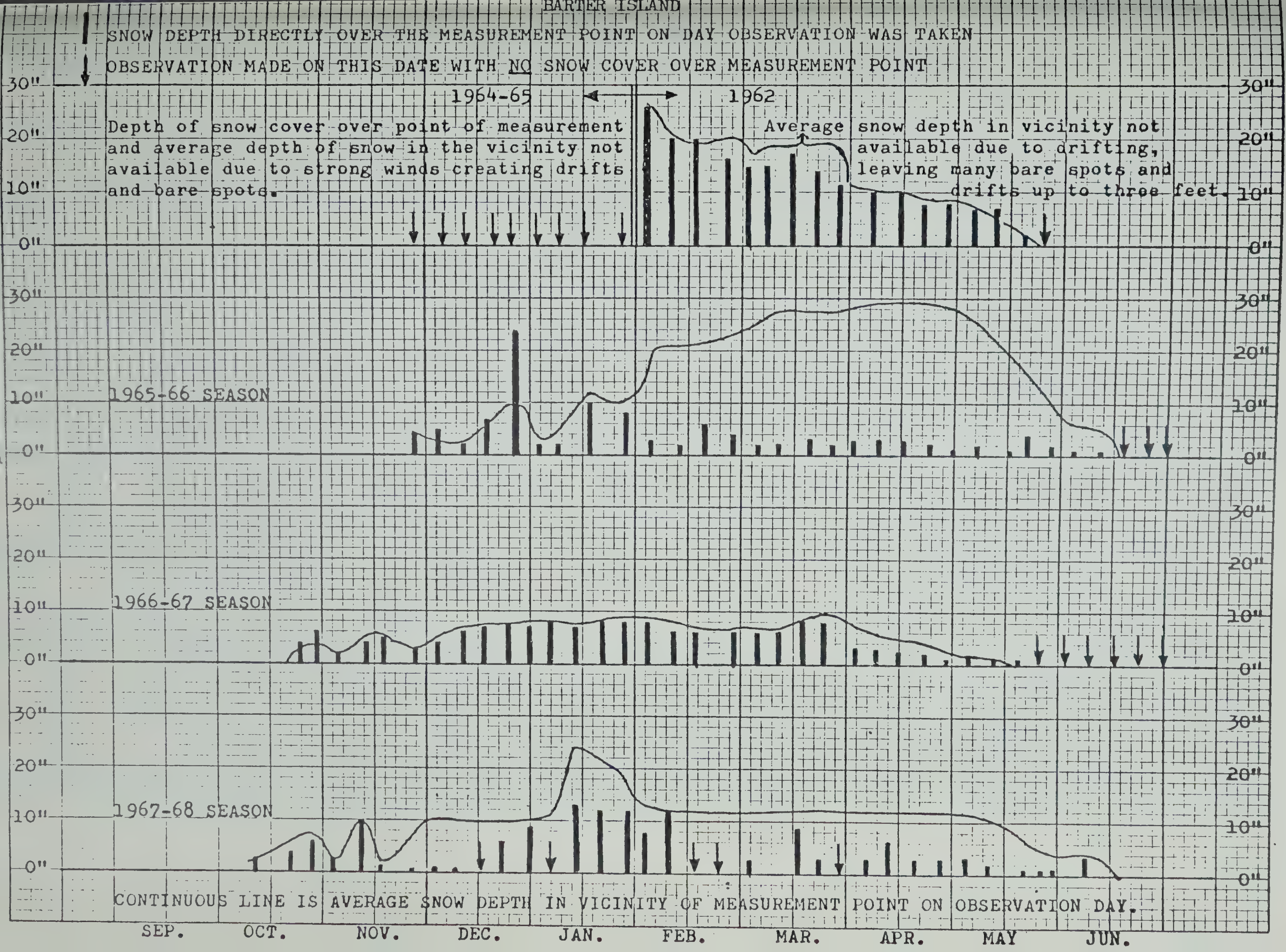
Despite the fact that there is no heating from the sun during 55 days of the winter at Barter Island and 66 days at Barrow, there is a daily diurnal temperature range of 12 to 15 degrees. February, the coldest month, normally experiences maximum and minimum temperatures of minus 10 to 15 degrees and minus 22 to 28 degrees respectively. Average wind speed during this month is between 10 and 15 mph. Considering the two together and computing the equivalent temperature or the temperature value that is actually affecting a worker, we have a possible range of minus 35 to 68 degrees. This is considerably colder than the actual. Extreme conditions have not been mentioned. At some time during the winter the temperature will drop to between a minus 35 to 45 degrees. Again using the average wind speed, the equivalent temperature will be between minus 65 and 90 degrees. It is unusual for the wind to be 10 to 15 mph during periods of extreme cold, but even a man walking produces a lower equivalent temperature. On a snowmobile or any type of open vehicle where a person is exposed to the free air, the conditions are the same as if the wind were blowing. The speed of the vehicle and the free air temperature will determine the equivalent temperature.

Precipitation in winter is light and does not appreciably affect working conditions. Sky cover does affect the temperature by slowing down radiation. Under clear skies a shallow but strong ground inversion forms, which also slows down the loss of heat to outer space. These two factors plus periodic flows of warmer air into the Arctic prevent the occurrence of even colder temperatures.

Figure 7 is a chart used in computing equivalent temperature.



BARTER ISLAND
70"
50"
30"
10"
70"
50"
30"
10"
1965-66
1967-68
1964-65
1962
1966-67
THE ABOVE LINES REPRESENT ICE THICKNESS OBSERVATIONS MADE ON A FRESH WATER LAKE ABOUT ONE MILE SOUTH OF THE WEATHER BUREAU STATION AT BARTER ISLAND, ALASKA.
LINES BELOW REPRESENT AVERAGE MONTHLY TEMPERATURE FOR YEARS INDICATED AND CORRESPOND TO THE PLOTS OF ICE OBSERVATIONS ABOVE.
40°F
20°F
0°F
-20°F
-40°F
40°F
20°F
0°F
-20°F
-40°F
"Normal" average monthly temperature (1931-60)
1967-68
1966-67
1962
1964-65
1965-66
SEP.
CCT.
NOV.
DEC.
JAN.
FEB.
MAR.
APR.
MAY
JUN.


BARTER ISLAND
SNOW DEPTH DIRECTLY OVER THE MEASUREMENT POINT ON DAY OBSERVATION WAS TAKEN
OBSERVATION MADE ON THIS DATE WITH NO SNOW COVER OVER MEASUREMENT POINT
1964-65
1962
Depth of snow cover over point of measurement and average depth of snow in the vicinity not available due to strong winds creating drifts and bare spots.
Average snow depth in vicinity not available due to drifting, leaving many bare spots and drifts up to three feet.
1965-66 SEASON
1966-67 SEASON
1967-68 SEASON
30"
20"
10"
0"
CONTINUOUS LINE IS AVERAGE SNOW DEPTH IN VICINITY OF MEASUREMENT POINT ON OBSERVATION DAY.
SEP.
OCT.
NOV.
DEC.
JAN.
FEB.
MAR.
APR.
MAY
JUN.

BARTER ISLAND

TABLE 1 Dates of and mean temperature on day of specified ice thicknesses

Season	10 inches		20 inches		30 inches		40 inches		50 inches		60 inches		70 inches		84 inches	
Fall-Winter	Date	Temp	Date	Temp	Date	Temp	Date	Temp	Date	Temp	Date	Temp	Date	Temp	Date	Temp
1962	-	-	-	-			Mar 7	-13	Mar 28	-9	Apr 18 (Max 58")	+1	-	-	-	-
1964-65	-	-	-	-	Nov 27	-9	Dec 15	-22	Jan 1	-22	Jan 19	-24	-	-	-	-
1965-66	-	-	-	-	Dec 5	-7	Dec 27	-15	Jan 19	-12	Mar 31	-15	Apr 2	-13	Apr 13	+2
1966-67	Oct 15	+18	Nov 5	+12	Nov 19	+6	Dec 19	-11	Jan 25	-14	Mar 8	-13	Apr 2 (Max 62")	-3	-	-
1967-68	Oct 15	+11	Nov 3	+3	Nov 21	-3	Dec 11	-7	Jan 16	-17	Mar 7	-14	Apr 1	-7	-	-
Average date and temp.	Oct 15	+15	Nov 4	+8	Nov 25	-3	Dec 18	-14	Jan 15	-16	Mar 11	-13	Apr 2	-10	Apr 13	+2

Season	84 inches		70 inches		60 inches		50 inches		40 inches		30 inches		20 inches		14 inches	
Spring-Summer	Date	Temp	Date	Temp	Date	Temp	Date	Temp	Date	Temp	Date	Temp	Date	Temp	Date	Temp
1962	-	-	-	-	Apr 30	+7	May 23	+21	-	-	-	-	-	-	-	-
1964-65	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1965-66	May 10	+15	Jun 6	+32	Jun 12	+35	Jun 18	+37	Jun 24	+38	Jun 29	+38	(no record)		-	-
1966-67	-	-	-	-	Apr 4	-2	Apr 28	+12	Jun 1	+30	Jun 19	+35	Jun 26	+36	Jun 29	+37
1967-68	-	-	Apr 14	-4	May 22	+26	May 30	+28	Jun 10	+32	Jun 17	+35	Jun 23	+36	Jun 29	+38
Average date and temp.	-	-	May 10	+14	May 10	+17	May 25	+25	Jun 12	+33	Jun 22	+36	Jun 24	+36	Jun 29	+38

Table 2. Climatological Data

for

Barter Island, Alaska

Air Temperature - F

Mean annual		10.4
Recorded high	(July 1947)	75
Recorded low	(Feb. 1950)	-59

Precipitation - inches

Mean annual		6.28
Max. annual	(1954)	16.44
Max. monthly	(Sept 1954)	4.91

Snowfall - inches

Mean annual		47.6
Max. annual	(1954-55)	115.4
Max. monthly	(Sept 1954)	35.8

Air freezing index (degree days. F. below 32)

Mean annual		8422
Minimum	(1962-63)	7278
Maximum	(1963-64)	9179

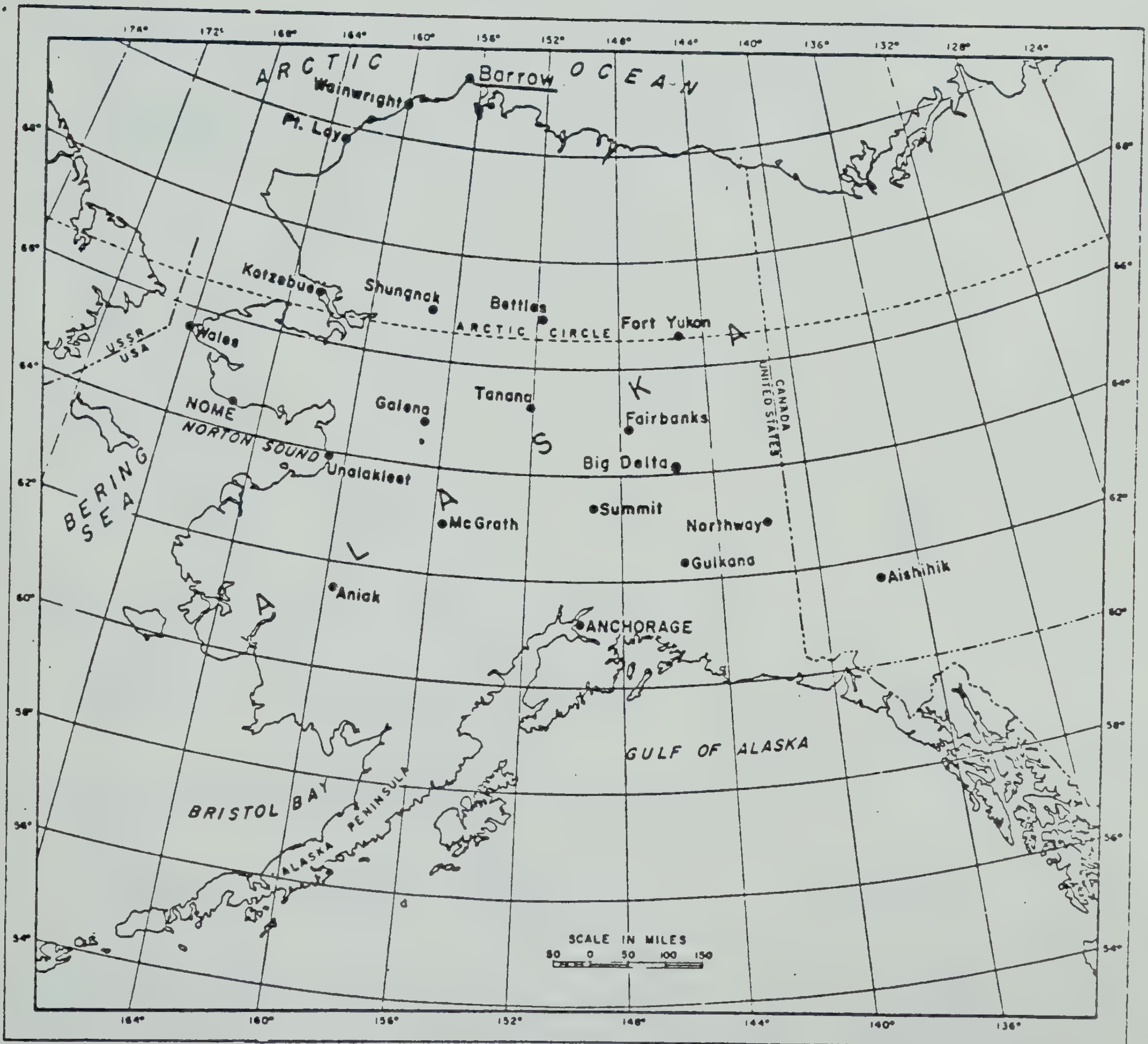
Air thawing index (degree-days. F. above 32)

Mean annual		605
Minimum	(1965)	294
Maximum	(1958)	1085

Average date start freeze season	6 Sept
Average date start thaw season	22 June
Average length of freeze season (days)	289
Average length of thaw season (days)	76

Snow Cover (inches) (1952-67)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Maximum recorded	16	18	20	21	18	7	0	1	4	8	10	13
Minimum recorded	12	15	17	16	8	0	0	0	0	2	7	9
16 year average	14	17	19	19	13	4	0	0	2	5	9	11



Sites where ground-temperature data are available from the Climatology office, Weather Bureau Regional Headquarters, Anchorage, Alaska

Table 3. Climatological Data

for

Barrow, Alaska

Air Temperature - F		
Mean annual		9.6
Recorded high	(July 1927)	78
Recorded low	(Feb. 1924)	-56
Precipitation - inches		
Mean annual		4.26
Max. annual	(1963)	9.77
Max. monthly	(Aug. 1963)	2.81
Snowfall - inches		
Mean annual		29.1
Max. annual	(1963)	62.1
Max. monthly	(Oct. 1925)	21.2
Air freezing index (degree-days. F. below 32)		
Average	(1947 - 1956)	8740
Minimum	(Sept 49 - Jun 50)	7614
Maximum	(Sept 46 - Jun 47)	9876
Air thawing index (degree-days. F. above 32)		
Average	(1947 - 1956)	532
Minimum	(Jun 55 - Aug 55)	241
Maximum	(Jun 54 - Sep 54)	918
Average date start freeze season		14 Sept
Average date start thaw season		11 June
Average length of freeze season (days)		271
Average length of thaw season (days)		94

Snow cover - inches

first day of month for 1952 - 1958

	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
Maximum recorded	3	3	7	14	20	19	20	23	24	21	0
Minimum recorded	0	0	2	3	5	6	6	7	6	0	0
6-year average	0	1	4	7	10	11	12	15	12	6	0

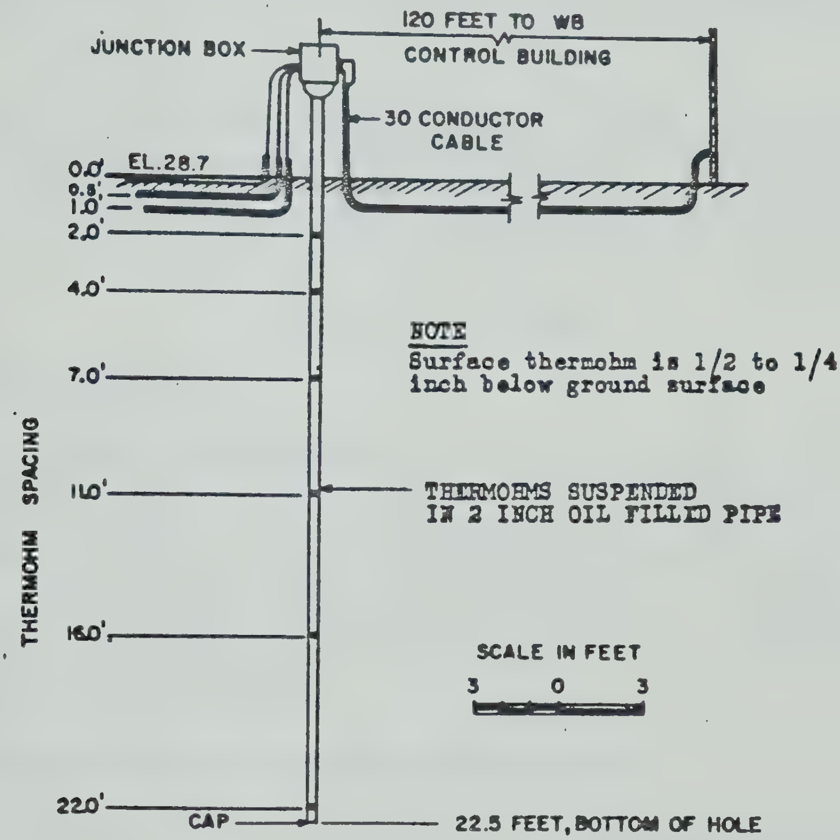


Figure 2. Resistance thermometer installation.

Temperature observations were made with a Leeds and Northrup Model 8010 temperature indicator; it was a Wheatstone-Bridge-type with a scale range of -50 to +120F.

Resistance thermometers were used instead of thermocouples because similar equipment had been used previously by the U. S. Weather Bureau and station personnel were familiar with the observational procedures involved.

SOIL INVESTIGATIONS

Exploration

In conjunction with drilling operations for the temperature well, representative soil samples were obtained with a 4-in. hand auger following each drill run. During a field trip to the site to remove equipment in October 1957, a 10.5 ft. deep exploratory hole was drilled 1 foot south of the temperature assembly. The exploratory drilling was performed by drive-sampling using a 200 lb. drop weight

driving 3 in. diameter hardened steel sample tubes and by a manually operated 30 lb. drop weight driving 1-1/8 in. diameter sample tubes. Attempts to sample below 10.5 feet resulted in refusal and backling of the sample tubes.

Soil data

Laboratory tests were performed to identify and classify the soil samples obtained, and moisture content and density tests were made on suitable representative samples. The boring log and soil data for the temperature well are shown in Figure 3 and the log and soil data for the exploratory hole are shown in Figure 4.

GROUND TEMPERATURES

Observed ground temperatures

Ground temperatures were received daily at Barrow for 11 years (1947-1957) with the exception of the period October 1948-July 1949 when observations were not obtained because of damage to the outside junction box. The 1957 observations were not included herein as their validity was questioned because of equipment deterioration. The maximum, minimum, and the average of the temperatures recorded the first day of each month are shown in Table 4. The actual ground temperatures recorded the first day of each month for the 1947-1956 period of observations are shown in Table 5.

Ground-temperature gradients and maximum-minimum curves

Ground-temperature gradients for a typical thaw and freeze season (1952-1953) at Barrow are shown in Figure 5. Gradients were plotted for the end-of-thaw, middle-of-thaw, middle-of-freeze and end-of-freeze. The maximum and minimum ground temperatures recorded at each depth during the period of record are also presented.

The end-of-thaw gradient indicates the maximum depth of thaw for the 1952 thawing season; the end-of-freeze gradient shows the minimum subsurface temperatures recorded (at depths greater than 4 feet) for the freezing season. It should be noted that the maximum and minimum temperatures shown for the various depths do not represent the 1952-1953 season as do the gradients; rather, they are the maximum and minimum temperatures recorded at each depth during the period of record.

Depth to permafrost

The seasonal depth of thaw at Barrow varied slightly from year to year; the average seasonal depth of thaw observed during the period of record of the ground-temperature observations was about 2.5 feet below the ground surface.

When the ground-temperature well was drilled on 19 July 1946, frozen ground was encountered at a depth of 1.6 feet (Fig. 3). The close-out exploration hole

drilled on 7 October 1957 was advanced entirely through frozen ground. The ground temperature data obtained during the period of record indicate a depth to permafrost of about 2.5 ft.

Meteorological data and ground isotherms for the period October 1950 through October 1951 are graphically shown in Figure 6.

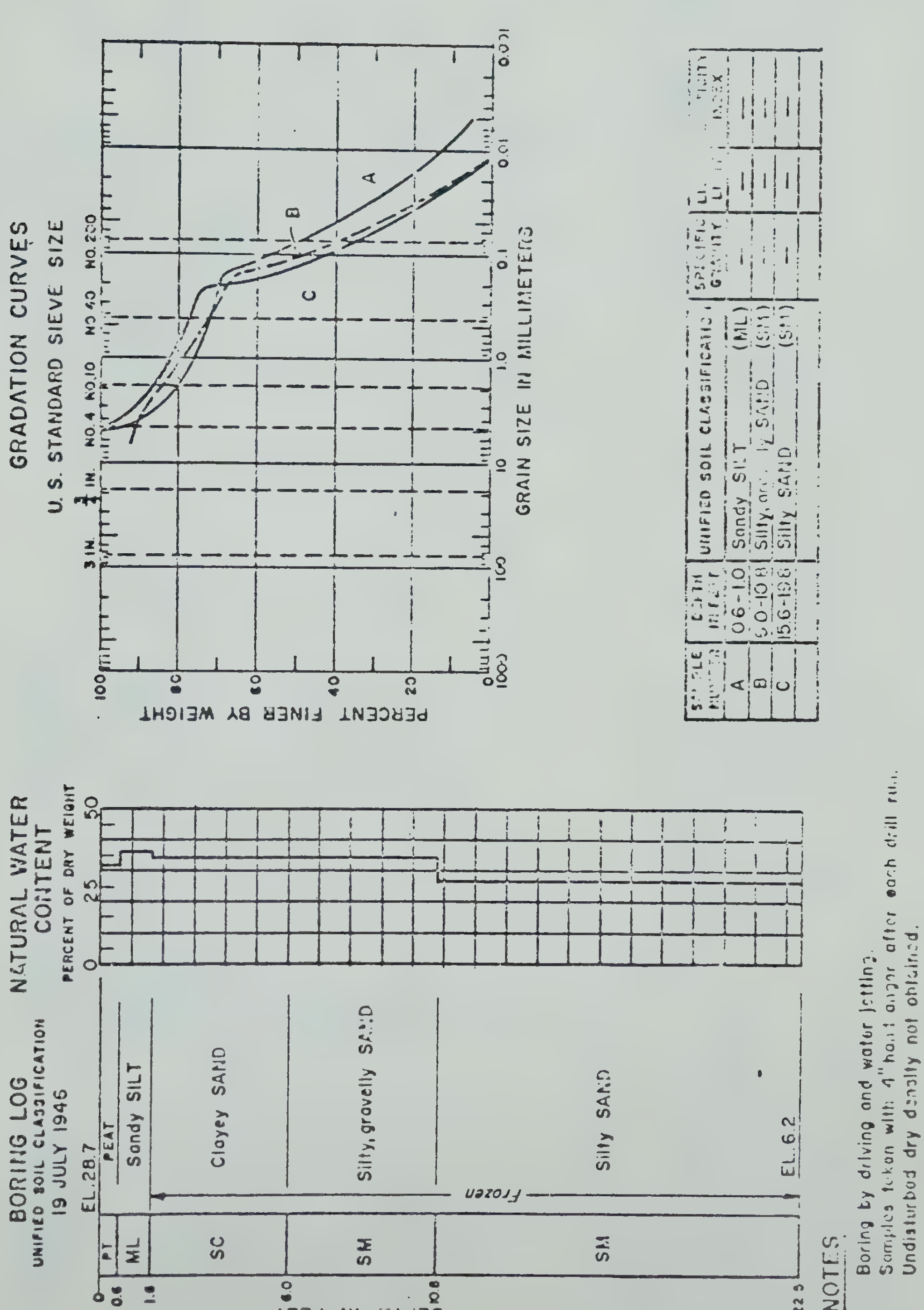
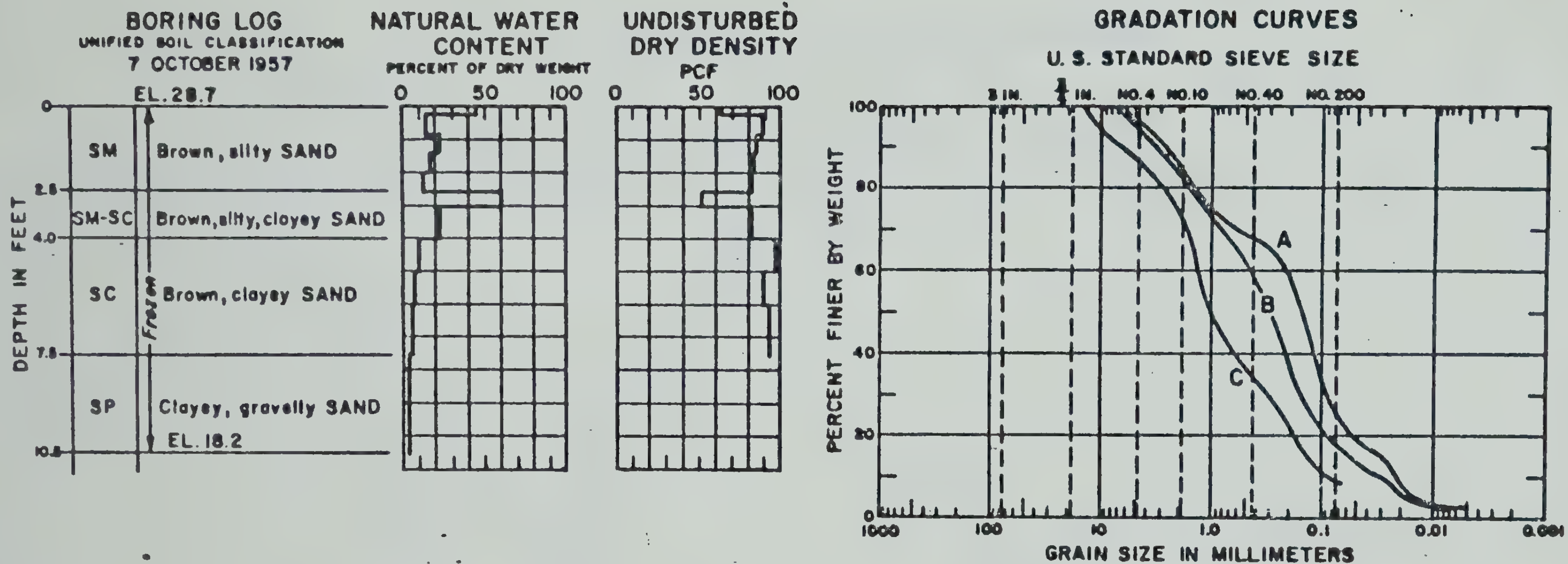


Figure 3. Boring log and soil data, ground-temperature well.



NOTES

Boring by drive-sampling with 3 inch diameter sample tube.

Attempts to sample below 10.5 feet resulted in refusal and buckling of the sample tube.

Undisturbed dry density not obtained below 7.5 feet.

SAMPLE NUMBER	DEPTH IN FEET	UNIFIED SOIL CLASSIFICATION	SPECIFIC GRAVITY	LIQUID LIMIT	PLASTICITY INDEX
A	0.8-1.4	Silty SAND (SM)	-	34.4	2.6
B	3.0-3.4	Silty, clayey SAND (SM-SC)	-	19.9	4.7
C	9.5-10.0	Clayey, gravelly SAND (SP)	-	-	-

Figure 4 Boring log and soil data, exploratory drilling.

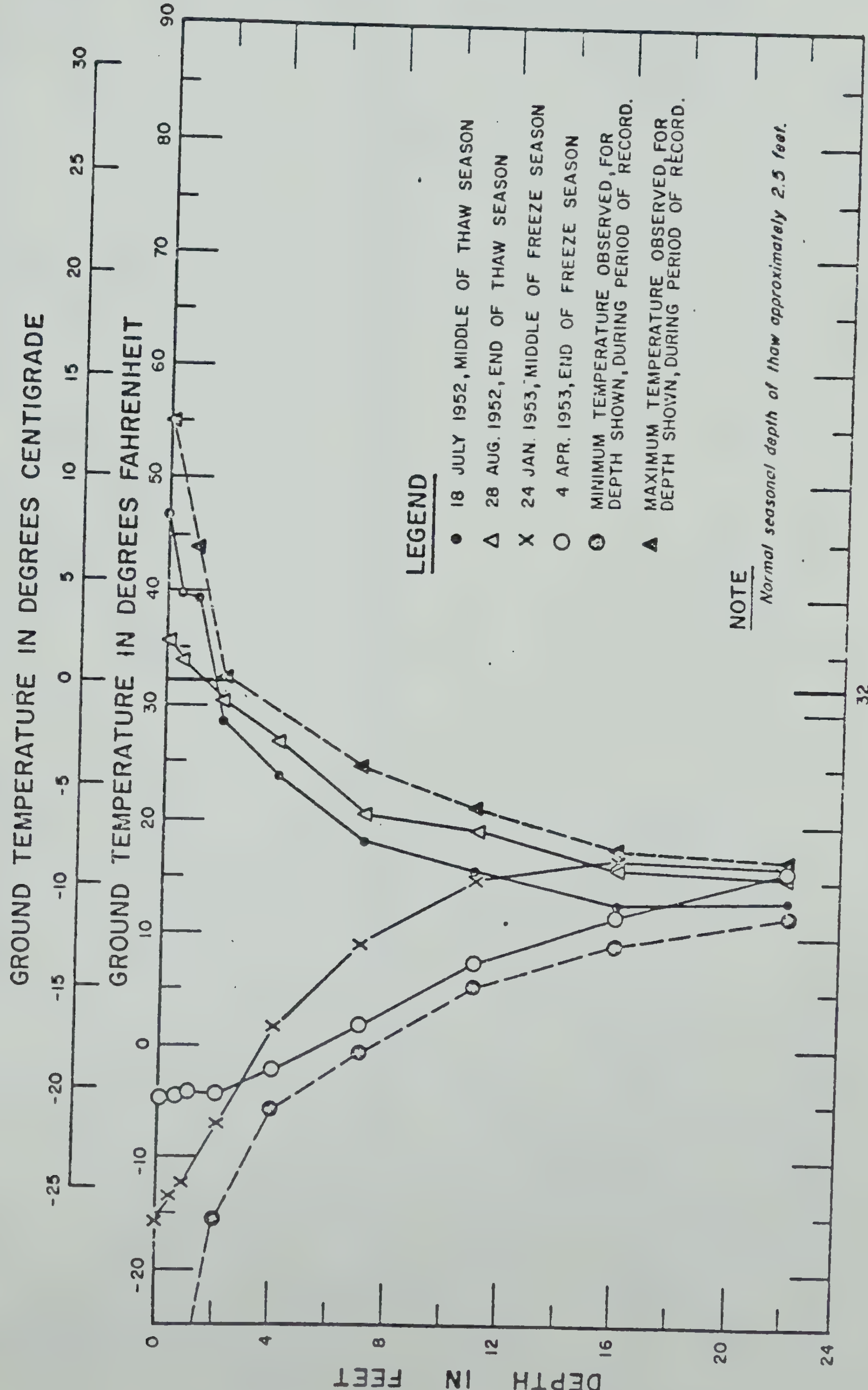


Figure 5. Ground-temperature gradients and maximum-minimum curves.

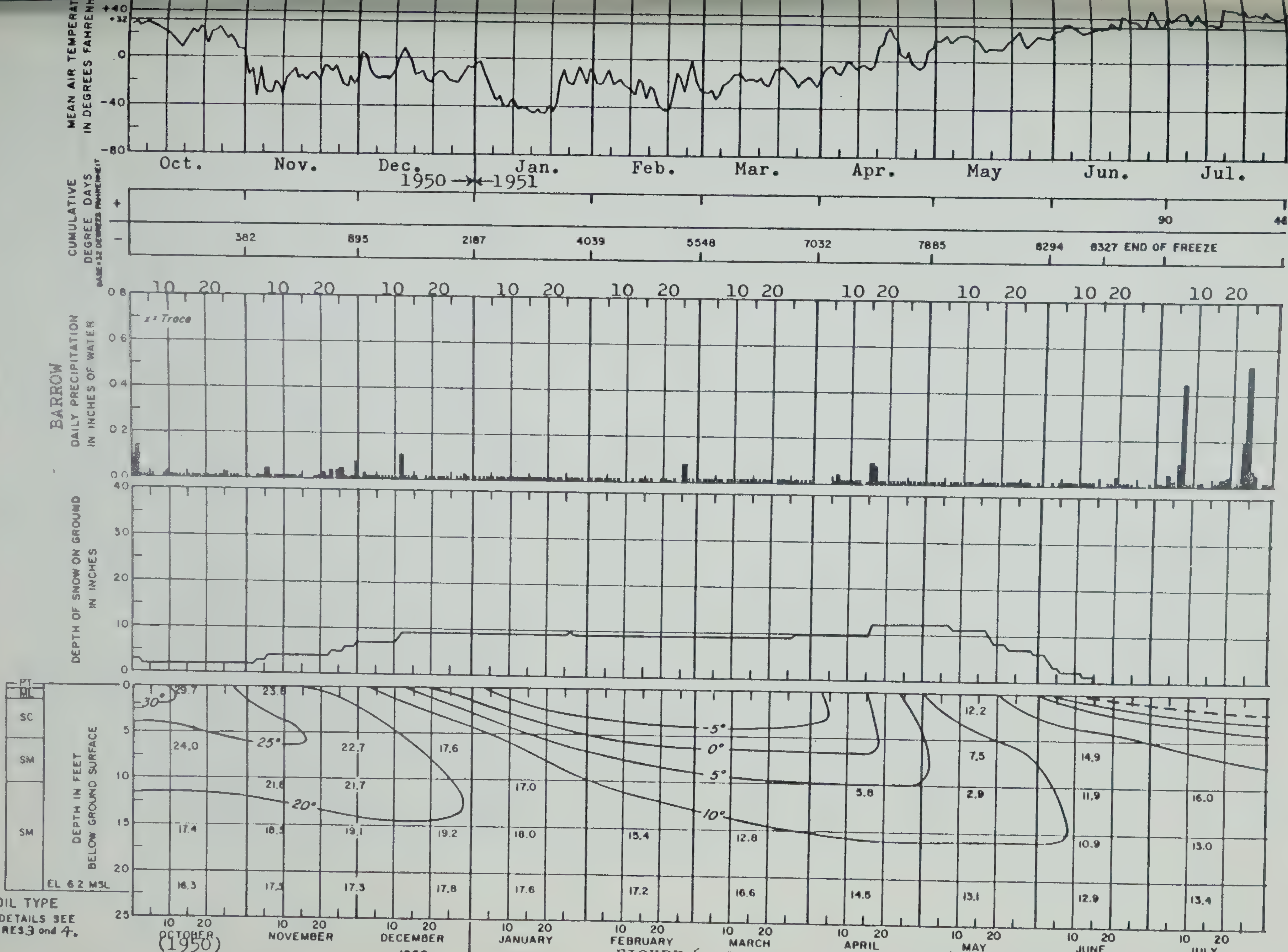


FIGURE 6. Meteorological data and ground isotherms

GROUND TEMPERATURE OBSERVATIONS

Table 4. Ground temperatures, °F, maximum, minimum and average observed first day of month, 1947-1956.

BARROW

DEPTH IN FEET	MONTH																	
	JANUARY			FEBRUARY			MARCH			APRIL			MAY			JUNE		
	MAX.	MIN.	AVG.	MAX.	MIN.	AVG.	MAX.	MIN.	AVG.	MAX.	MIN.	AVG.	MAX.	MIN.	AVG.	MAX.	MIN.	AVG.
0.0*	12.0	-9.9	-2.1	9.2	-13.9	-6.5	5.8	-17.0	-7.5	5.2	-9.9	-2.3	12.4	6.9	6.1	32.0	18.1	27.6
0.5	11.1	-8.4	-1.4	9.3	-12.5	-5.3	5.0	-17.0	-7.0	5.1	-9.1	-1.9	11.9	6.8	6.2	30.8	11.4	25.5
1.0	12.2	-8.1	-0.7	9.9	-11.1	-3.9	6.1	-15.8	-5.9	4.6	-8.3	-1.6	11.1	7.0	6.1	28.7	13.2	25.0
2.0	12.2	-6.9	2.7	11.0	-5.9	-0.1	6.2	-13.0	-2.9	6.3	-5.8	0.0	8.8	6.6	5.6	23.8	11.7	18.8
4.0	15.8	2.0	8.9	13.0	-1.7	3.8	11.0	-5.8	1.2	8.5	-2.8	2.2	9.0	5.3	7.0	18.9	12.0	15.8
7.0	17.2	8.0	13.8	15.2	4.0	8.1	13.0	0.7	5.8	10.9	0.9	4.6	9.6	4.2	6.8	16.4	10.0	12.5
11.0	21.0	13.9	18.1	18.0	10.0	13.7	15.2	7.1	10.9	14.1	4.2	8.5	11.9	5.4	8.6	13.4	9.0	11.0
16.0	19.8	16.6	18.4	18.5	13.9	15.9	16.0	11.6	14.0	15.5	9.1	12.2	13.7	8.3	10.9	12.6	9.6	11.3
22.0	18.2	16.4	17.4	18.1	16.4	15.1	17.9	15.3	16.7	16.4	13.7	15.4	16.3	12.7	14.2	14.8	12.1	13.5

DEPTH IN FEET	MONTH																	
	JULY			AUGUST			SEPTEMBER			OCTOBER			NOVEMBER			DECEMBER		
	MAX.	MIN.	AVG.	MAX.	MIN.	AVG.	MAX.	MIN.	AVG.	MAX	MIN.	AVG.	MAX.	MIN.	AVG.	MAX.	MIN.	AVG.
0.0*	48.1	34.8	41.1	50.0	34.6	40.3	40.2	27.0	34.2	31.8	23.4	28.3	29.0	9.8	17.3	15.9	0.0	9.3
0.5	40.2	30.2	35.4	43.5	32.4	36.9	38.2	28.7	33.5	31.6	23.3	28.5	29.1	10.9	18.4	17.4	0.1	9.9
1.0	39.1	30.1	34.3	42.5	33.2	36.7	37.2	24.3	32.6	31.5	27.3	30.0	30.0	10.0	18.1	18.5	0.9	11.0
2.0	28.0	24.8	27.1	31.5	21.1	29.3	32.9	29.1	30.5	30.8	26.2	29.5	29.4	13.2	20.9	20.1	2.9	13.7
4.0	23.9	21.8	22.9	27.2	24.7	25.8	28.8	26.3	27.2	28.4	24.0	27.0	28.0	19.0	23.9	24.1	8.9	17.1
7.0	19.0	15.6	17.4	22.2	19.6	21.2	24.2	21.9	22.9	24.4	22.0	23.5	25.0	22.1	23.6	24.1	13.2	19.5
11.0	15.5	13.1	14.2	19.0	16.1	17.4	20.8	17.1	19.0	21.2	19.3	20.2	21.9	20.9	21.4	21.9	17.6	20.1
16.0	13.2	12.0	12.7	16.2	13.3	14.6	17.1	13.6	15.7	17.8	16.2	17.0	18.9	17.0	18.0	19.1	18.0	18.6
22.0	14.8	13.0	13.7	14.9	14.0	14.4	16.0	14.6	15.0	16.1	15.3	15.8	17.3	16.0	16.7	17.9	16.7	17.2

*Thermohm installed $\frac{1}{8}$ inch to $\frac{1}{4}$ inch below ground surface.

GROUND TEMPERATURE OBSERVATIONS
BARROW

DEPTH IN FEET	1951 JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.
0.0	-0.1	-13.9	-17.0	-8.1	12.4	28.8	42.4	50.0	35.8	28.2	29.0	14.0
0.5	0.3	-12.5	-17.0	-8.0	11.9	24.8	40.2	43.5	34.3	29.0	29.1	14.9
1.0	0.6	-11.1	-15.8	-7.6	11.1	24.1	39.1	42.5	34.7	30.4	30.0	15.8
2.0	4.8	- 5.9	- 9.5	-5.3	6.6	15.4	27.9	31.5	31.0	29.8	29.4	20.0
4.0	10.0	- 1.7	4.7	-2.8	5.3	13.2	22.8	26.1	27.3	27.0	28.0	24.1
7.0	15.7	4.6	1.2	1.1	5.0	10.0	16.3	21.6	22.0	22.7	24.3	24.1
11.0	19.9	12.9	8.7	6.8	6.9	9.2	14.1	17.3	18.4	19.3	21.1	21.4
16.0	19.1	17.0	13.7	11.6	9.5	9.6	12.2	13.3	13.6	16.2	17.6	18.4
22.0	17.9	17.2	16.8	15.8	13.9	12.3	13.3	14.2	14.8	15.4	16.0	16.7

DEPTH IN FEET	1952 JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.
0.0	12.0	9.2	5.8	4.2	6.9	18.1	39.7	34.6	32.9	23.4	12.2	8.0
0.5	11.1	9.3	5.0	4.6	7.8	11.4	31.3	35.2	33.1	23.4	13.3	7.9
1.0	12.2	9.9	6.1	4.6	7.0	13.2	30.1	36.1	32.2	27.3	13.8	8.3
2.0	12.2	11.0	6.2	6.3	8.0	11.7	26.8	30.0	30.8	29.2	20.2	12.5
4.0	15.8	13.0	11.0	8.5	9.0	12.0	21.8	25.3	27.0	26.3	24.0	17.4
7.0	17.2	15.2	13.0	10.9	9.6	10.7	15.6	19.6	21.9	23.2	24.0	19.1
11.0	21.0	18.0	15.2	14.1	11.9	9.0	15.2	16.1	18.5	19.8	21.5	18.6
16.0	18.9	18.5	16.0	15.5	13.7	11.4	13.2	13.9	15.6	17.4	18.4	18.2
22.0	17.2	18.0	17.7	16.4	16.3	13.3	14.8	14.6	14.7	15.3	17.3	17.7

DEPTH IN FEET	1953 JAN	FEB	MAR	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.
0.0	0.3	-6.8	-7.8	-6.2	9.0	30.2	39.8	44.5	31.6	30.6	9.8	7.0
0.5	0.9	-6.1	-7.4	-5.9	8.9	28.9	35.1	41.9	28.7	29.7	11.2	7.1
1.0	1.2	-5.9	-7.2	-5.8	9.1	28.8	34.6	41.3	31.1	30.9	12.1	9.2
2.0	3.3	-4.1	-5.8	-4.3	7.8	22.3	27.8	30.1	29.2	29.9	17.1	12.0
4.0	8.7	0.6	-1.8	-1.2	6.3	17.5	23.9	26.1	26.3	27.8	22.2	13.8
7.0	14.2	6.8	3.4	2.2	5.6	12.8	17.8	21.8	22.0	23.0	23.0	17.2
11.0	18.6	13.9	9.9	6.8	7.2	10.6	13.3	17.7	18.3	20.0	21.3	17.6
16.0	18.6	16.7	14.1	10.6	10.0	10.6	12.8	14.9	14.7	17.0	18.0	18.0
22.0	18.2	17.7	16.8	15.0	14.0	12.9	13.6	14.3	14.4	15.3	16.5	16.8

DEPTH IN FEET	1954 JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.
0.0	-5.0	-4.8	-4.0	5.2	9.5	29.2	42.9	37.8	40.2	31.8	26.8	12.0
0.5	-2.8	-3.0	-3.9	5.1	10.0	27.3	36.2	36.2	38.2	31.6	28.8	12.2
1.0	-4.2	-2.5	-5.5	4.5	10.4	25.4	37.3	35.9	37.2	31.5	28.9	13.1
2.0	3.1	1.0	-1.6	4.4	8.8	20.5	24.8	31.2	32.9	30.8	28.0	14.1
4.0	8.3	5.0	1.6	3.8	7.1	18.8	22.7	27.2	28.8	28.4	27.9	18.0
7.0	13.0	7.7	6.9	4.9	7.7	16.4	18.1	22.2	24.2	24.1	24.4	19.2
11.0	15.2	12.0	11.2	5.5	9.0	13.4	14.4	19.0	20.8	21.2	21.3	21.9
16.0	17.6	14.9	14.4	11.8	10.7	12.6	12.8	16.2	17.0	17.0	18.0	19.1
22.0	16.4	16.5	16.9	15.1	13.8	13.4	13.8	14.9	15.9	16.1	16.4	17.1

Table 5. (Cont'd) Ground temperatures, °F, recorded first day of month, 1947-1956.

DEPTH IN FEET	1955											
	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.
0.0	-1.0	-13.9	-10.9	-9.9	9.1	30.7	36.0	36.2	31.9	30.9	10.7	0.0
0.5	-2.1	-11.2	-8.8	-9.1	8.9	29.5	34.0	34.9	31.8	30.9	10.9	0.1
1.0	0.0	-6.2	-7.2	-8.3	8.7	29.3	32.2	34.2	31.6	31.0	11.1	0.9
2.0	3.2	0.0	-4.0	-5.8	8.2	23.8	27.6	30.1	30.6	30.0	13.2	2.9
4.0	8.8	5.2	-1.8	-1.0	6.9	18.6	23.8	26.9	28.0	28.0	19.0	8.9
7.0	14.2	7.0	3.1	3.0	6.1	13.7	17.7	21.9	23.9	24.1	22.1	13.2
11.0	20.0	16.1	11.0	8.3	8.2	11.6	15.5	17.9	20.2	20.9	21.9	18.1
16.0	19.8	17.0	15.1	12.6	11.0	11.2	13.2	15.1	17.1	17.8	18.9	18.9
22.0	17.6	18.1	17.9	16.1	14.8	14.1	14.0	14.9	16.0	16.1	16.9	17.9

DEPTH IN FEET	1956											
	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.
0.0	-9.1	-5.1	-12.8	-3.3	11.4	25.1	34.8	35.1	27.0	25.3	13.1	-
0.5	-8.2	-5.0	-12.3	-3.2	10.8	24.2	30.0	29.6	30.1	29.4	16.0	-
1.0	-8.1	-4.9	-12.1	-3.0	10.3	24.0	32.0	33.7	24.3	27.8	10.0	-
2.0	-6.9	-5.0	-13.0	-3.2	8.3	22.0	28.0	21.1	29.1	26.2	13.4	-
4.0	2.0	0.0	-5.8	-1.6	5.3	18.9	23.8	25.6	27.3	26.9	20.2	-
7.0	8.0	4.0	0.7	0.9	4.2	14.1	19.0	21.5	23.5	24.4	23.0	-
11.0	13.9	10.0	7.1	4.2	5.4	11.2	13.2	17.0	17.1	20.4	20.9	-
16.0	16.6	13.9	11.6	9.1	8.3	10.2	12.0	14.7	15.7	16.4	17.0	-
22.0	17.1	16.8	15.3	13.7	12.7	12.1	13.0	14.0	15.0	16.1	16.8	-

DEPTH IN FEET												
	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.
0.0												
0.5												
1.0												
2.0												
4.0												
7.0												
11.0												
16.0												
22.0												

DEPTH IN FEET												
	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.
0.0												
0.5												
1.0												
2.0												
4.0												
7.0												
11.0												
16.0												
22.0												

Table 5 (Cont'd) Ground temperatures, °F, recorded first day of month, 1947-1956.

DEPTH IN FEET	1947 JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
0.0	-3.2	-10.3	-0.5	2.9	7.1	32.0	48.1	43.1	38.2	25.6	17.2	8.0
0.5	-2.7	-6.3	0.1	3.8	7.2	30.8	40.2	39.8	38.0	23.3	17.9	9.9
1.0	-1.4	-3.2	0.9	4.4	7.5	28.7	33.9	36.2	35.6	29.6	18.2	10.8
2.0	2.7	1.2	3.0	5.2	7.2	21.3	26.8	30.1	30.3	30.0	21.2	14.1
4.0	7.8	5.3	5.3	6.5	7.7	16.0	22.4	26.2	26.5	27.8	23.0	17.1
7.0	13.7	9.8	8.4	7.3	8.2	12.2	18.1	21.2	22.8	23.9	23.2	20.0
11.0	17.8	13.9	12.1	11.0	10.2	11.6	14.5	17.3	19.2	20.1	21.1	20.1
16.0	17.9	15.7	14.5	12.9	11.7	12.3	13.2	15.0	15.7	17.2	17.9	18.5
22.0	16.8	16.4	16.5	15.2	13.8	14.4	13.6	14.4	14.7	16.0	16.2	17.0

DEPTH IN FEET	1948* JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
0.0	-2.6	-7.5	-8.2	-1.5	7.1	29.1	-	42.1	31.8			
0.5	-1.1	-6.1	-7.2	-1.0	6.8	27.3	-	38.2	31.8			
1.0	-0.2	-5.4	-5.4	-0.2	7.0	26.3	-	37.4	31.8			
2.0	-	0.3	1.1	1.9	6.6	16.3	-	30.1	30.0			
4.0	11.2	4.0	5.2	4.7	7.2	12.5	-	25.3	27.2			
7.0	15.6	8.8	8.7	7.1	8.1	11.2	-	20.8	23.1			
11.0	18.1	13.0	12.0	10.9	10.2	10.8	-	17.3	19.2			
16.0	18.2	15.4	14.1	13.2	12.2	11.4	-	14.5	15.7			
22.0	17.5	16.6	16.3	15.3	14.6	13.9	-	14.1	15.0			

DEPTH IN FEET	1949* JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
0.0								43.6	34.9	32.7	-	-1.6
0.5								38.8	36.6	31.8	-	0.8
1.0								37.3	35.3	31.8	-	1.5
2.0								29.3	30.6	30.7	-	11.0
4.0								25.1	27.0	24.0	-	15.7
7.0								20.6	22.8	22.0	-	20.8
11.0								17.2	19.3	20.1	-	21.7
16.0								14.0	16.2	17.0	-	18.8
22.0								14.3	14.6	15.9	-	17.2

DEPTH IN FEET	1950 JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
0.0	-9.9	-5.0	-7.8	-4.1	-	25.3	45.0	40.2	38.0	30.3	19.3	15.9
0.5	-8.4	-7.1	-7.3	-3.0	-	25.0	35.9	32.4	35.2	30.8	20.0	17.4
1.0	-6.6	-5.8	-7.0	-2.1	-	25.0	35.1	33.2	35.1	31.3	20.6	18.5
2.0	-0.6	-4.6	-2.8	0.8	-	16.2	27.2	29.6	30.5	30.0	24.8	20.1
4.0	7.9	3.2	1.6	3.2	-	14.4	22.2	24.7	26.7	27.3	27.2	21.8
7.0	12.7	9.0	6.9	4.1	-	11.2	16.8	20.7	22.5	23.8	25.0	22.5
11.0	18.2	13.8	11.2	9.1	-	11.6	13.1	17.0	18.8	20.4	21.8	21.7
16.0	19.2	14.4	12.9	12.7	-	12.5	12.4	14.8	15.9	17.2	17.8	19.1
22.0	17.7	16.5	16.3	15.6	-	14.8	13.4	14.0	15.2	16.1	17.2	17.3

*No observations obtained October 1948-July 1949 because of damage to equipment.

Table 5. Ground temperatures, °F, recorded first day of month, 1947-1956.

WIND SPEED		COOLING POWER OF WIND EXPRESSED AS "EQUIVALENT CHILL TEMPERATURE"																				
KNOTS	MPH	TEMPERATURE (F)																				
CALM	CALM	40	35	30	25	20	15	10	5	0	-5	-10	-15	-20	-25	-30	-35	-40	-45	-50	-55	-60
		EQUIVALENT CHILL TEMPERATURE																				
3-6	5	35	30	25	20	15	10	5	0	-5	-10	-15	-20	-25	-30	-35	-40	-45	-50	-55	-65	-70
7-10	10	30	20	15	10	5	0	-10	-15	-20	-25	-35	-40	-45	-50	-60	-65	-70	-75	-80	-90	-95
11-15	15	25	15	10	0	-5	-10	-20	-25	-30	-40	-45	-50	-60	-65	-70	-80	-85	-90	-100	-105	-110
16-19	20	20	10	5	0	-10	-15	-25	-30	-35	-45	-50	-60	-65	-75	-80	-85	-95	-100	-110	-115	-120
20-23	25	15	10	0	-5	-15	-20	-30	-35	-45	-50	-60	-65	-75	-80	-90	-95	-105	-110	-120	-125	-135
24-28	30	10	5	0	-10	-20	-25	-30	-40	-50	-55	-65	-70	-80	-85	-95	-100	-110	-115	-125	-130	-140
29-32	35	10	5	-5	-10	-20	-30	-35	-40	-50	-60	-65	-75	-80	-90	-100	-105	-115	-120	-130	-135	-145
33-36	40	10	0	-5	-15	-20	-30	-35	-45	-55	-60	-70	-75	-85	-95	-100	-110	-115	-125	-130	-140	-150
WINDS ABOVE 40 HAVE LITTLE ADDITIONAL EFFECT		LITTLE DANGER					INCREASING DANGER (Flesh may freeze within 1 minute)							GREAT DANGER (Flesh may freeze within 30 seconds)								
		DANGER OF FREEZING EXPOSED FLESH FOR PROPERLY CLOTHED PERSONS																				

Figure 7.